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COMPETITION BETWEEN STIMULUS-REINFORCER CONTINGENCIES AND ANTICIPATORY CONTRAST

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Procedures used to study anticipatory contrast are conceptually similar to those used to study autoshaping, in that two target stimuli signal either higher or lower rates of reinforcement in the following components of the schedule. Despite this signal contingency, anticipatory contrast entails response rates that are higher to the target stimulus followed by the lower rate of reinforcement. To determine the relation between such effects and autoshaping, different variations of the procedure were used in which the signal contingency was presented in the absence of reinforcement in the target components themselves and in which the reinforcement schedules in the different following components were signaled by the same stimulus. Autoshaping effects of this signal contingency were demonstrated when no reinforcement was available during the target-component signals themselves. Intermediate patterns of behavior occurred when reinforcement was available during the target-component signals and when their different following schedules were correlated with the same stimulus. Attempts to isolate these signal and contrast effects functionally by using the signal-key procedure were unsuccessful. The results demonstrate that Pavlovian stimulus contingencies are in competition with the dynamics of anticipatory contrast, thus reducing its occurrence under some circumstances.

Key words: behavioral contrast, autoshaping, anticipatory contrast, multiple schedules, signal-key procedure, key peck, pigeons

A significant portion of behavioral contrast in steady-state behavior is anticipatory in nature. Response rates in a target component vary inversely with reinforcement rates in the following component when the schedule preceding the target component is held constant (Williams, 1979; Wilton & Gay, 1969). When both the preceding and following schedules are varied simultaneously, the effect of the following schedule is substantially greater than the effect of the preceding schedule (Williams, 1981; Williams & Wixted, 1986).

Contrast effects due to the following schedule (hereafter referred to as anticipatory contrast) are paradoxical in view of the Pavlovian contingencies that are embedded in the procedure. Consider two target components with identical schedules, one of which leads to a higher valued following schedule and one which leads to extinction (EXT). Contrast effects imply that response rate will be higher in the latter. But the Pavlovian contingencies predict the reverse effect: Higher response rates should occur in the target leading to the higher valued schedule because the stimulus–reinforcer contingency between the cue for the target component and the subsequent high rate of reinforcement should produce autoshaped pecks that add to the operant baseline.

The importance of Pavlovian contingencies in a procedure similar to that used to produce anticipatory contrast has been demonstrated by Brown, Hemmes, Coleman, Hassin, and Goldhammer (1982). They trained pigeons on a four-component schedule in which two target components were correlated with extinction (EXT) but led to different schedules during a white keylight. Following Target Component A was a variable-interval (VI) schedule during the white keylight; following Target Component B, the schedule during the white keylight was EXT. Because the schedule during the white keylight could be determined only by the preceding component, the stimuli correlated with Components A and B thus served as Pavlovian positive conditioned stimuli (CS+) and negative conditioned stimuli (CS−), respectively. In keeping with that contingency, substantial key pecking was maintained in Component A, despite its own schedule being EXT.

The procedure used by Brown et al. (1982) differs from the usual anticipatory contrast

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procedure in two important dimensions. First, in the Brown et al. procedure the only cues for the value of the different following schedules were the stimuli during the two target components, whereas during anticipatory contrast procedures the different following schedules were themselves correlated with different stimuli. Second, the procedure of Brown et al. had no food reinforcement available during the target components, whereas food schedules are available in anticipatory contrast procedures. Both of these variables may play an important role, the former by causing variation in the degree of predictiveness of the target-component stimuli for the different following schedules and the latter by providing a different reinforcement rate that may be compared to the other schedules in the situation.

Williams (1990) investigated the role of the Pavlovian stimulus contingency in the anticipatory contrast procedure by comparing the results of the procedure with versus without different stimuli correlated with the different following schedules. When different stimuli were used, robust anticipatory contrast occurred, but when the same stimulus was used for both following schedules, contrast was reduced, and some subjects responded with a higher rate in the target component leading to the higher valued schedule (i.e., an autoshaping effect). Thus, the strength of the Pavlovian stimulus–reinforcer contingency appeared to be critically important; when it was very strong, the autoshaping effects dominated the contrast effect that otherwise occurred. However, there was a great deal of between-subject variability in the pattern of results.

The present study extends the investigation of Williams (1990) by examining both the effects of the stimuli correlated with the different following schedules and the role played by the reinforcement schedules during the target components themselves. During the first phase of training, the procedure used by Brown et al. (1982) was replicated, in that no food schedules were available during the target components and the different following schedules were associated with the same stimulus. During the second phase, food schedules were added during the target components themselves while the stimuli were kept constant; during the third phase, different stimuli were added that were correlated with the different following schedules. At issue was the effect of these different procedural manipulations and the point in training in which the autoshaping effect would be replaced by the anticipatory contrast effect.

EXPERIMENT 1

METHOD

Subjects

Four experimentally naive White Carneau pigeons were maintained at 80% of their free-feeding body weights by additional feeding, when necessary, after each experimental session. All were housed in individual cages with water and grit freely available.

Apparatus

Four identical three-key operant conditioning chambers were used. Their internal dimensions were 36 cm wide by 32 cm long by 35 cm high. All walls were opaque gray plastic except the front, which was sheet aluminum. Mounted on the front wall were three translucent response keys (2.5 cm diameter) 26 cm above the floor and 7.25 cm apart, center to center. Each key required a force of approximately 0.15 N to operate and could be transilluminated from the rear by standard IEE 28-V 12-stimulus projectors. A 28-V 1-W miniature lamp was located 8.75 cm above each response key, and the rightmost of these lamps provided general chamber illumination. Directly below the center key and 9.5 cm above the floor was an opening (5.7 cm by 5 cm) that provided access to a solenoid-operated grain hopper. When activated, the hopper was illuminated from above with white light by a 28-V 1-W miniature lamp. A 5-cm speaker was mounted above the center of the ceiling and provided continuous white noise throughout the experimental sessions. Experimental events in each chamber were controlled by microcomputers located in an adjacent room.

Procedure

During the first two sessions, all subjects were trained on an autoshaping procedure in which the center key was illuminated with a white vertical line. After responding had been established, they were begun on a four-component multiple schedule in which the two target components, A and B, were arranged in pairs with their respective following components, X and Y, with the A-X and B-Y pairs then randomly interspersed throughout an experimental session, according to a probability generator. Thus, the two target components were, on average, preceded equally often by X and Y, but were consistently followed by different components. The stimuli for the different components of the schedule were associated with blue and yellow for Components A and B (counterbalanced over subjects), and a white vertical line for Components X and Y. During Components A, B, and Y, no reinforcement was available, whereas a VI 30-s schedule operated during Component X. Components A and B were always 10 s in duration; Components X and Y were 30 s in duration. Training continued during Phase 1 for 20 sessions, each of which continued for 40 exposures to each component of the schedule (approximately 33 min).

During Phase 2, the only change in procedure was that a VI 2-min schedule was added during Components A and B. All other schedules and stimulus assignments remained the same. Training continued for 25 sessions.

During Phase 3, the only change was that the stimulus for Component Y, correlated with EXT, was changed from the white vertical line to a small white circle. Training continued for 25 to 35 sessions, depending on the stability of performance for individual subjects.

During Phase 4, the conditions returned to the same as Phase 2; the stimulus during Component Y returned to the white vertical line, causing the cues for Components X and Y to be the same once again. Training continued for 20 sessions.

During Phase 5, the stimuli for Components A and B were changed to red and green (again counterbalanced over subjects) and were moved from the center key to the left side key of the chamber. The center key was not illuminated during these components, and pecks to it had no scheduled effect. The stimulus correlated with Components X and Y continued to be the vertical line on the center key. The schedules during Components A and B continued to be VI 2 min, whereas VI 30 s operated during Component X and EXT operated during Component Y. Training continued for 25 sessions.

Results

Figure 1 shows the response rates during Components A and B, which differed only with respect to their different following schedules. Also shown is a discrimination index for the behavior during the two following schedules, X versus Y, which reflects the degree to which the VI 30-s versus EXT schedules were discriminated. The discrimination measure was calculated by summing the response rates during Components X and Y and determining the percentage of those responses that occurred

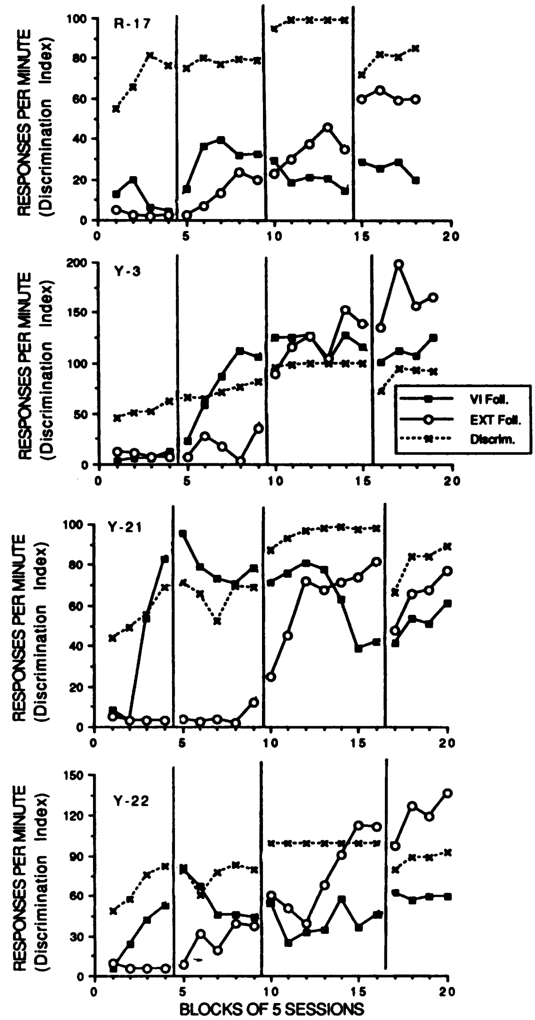

Fig. 1. Results from individual subjects in Experiment 1. Shown are the response rates in the target component followed by the higher valued VI (Component A) and those in the target component followed by EXT (Component B). Also shown is the percentage of the total responses in Components X and Y that occurred in Component X. Separate panels of the data for each subject, separated by the vertical lines, correspond to Phases 1 through 4 of training.

Table 1

Response rates (responses per minute) in the target components (A vs. B) and during Component X (correlated with the VI 30-s schedule) during the last five sessions of each condition in Experiment 1. Also shown is the discrimination index for responding in Components X versus Y (percentage responses in Component X). Standard deviations of the response rates across the last five sessions are shown in parentheses.

Subject		Phase 1	Phase 2	Phase 3	Phase 4
R-17	A	5 (1.7)	32 (5.0)	15 (6.1)	20 (6.0)
	B	2 (1.1)	20 (4.3)	35 (9.4)	60 (6.9)
	X	51 (13.5)	36 (9.3)	38 (4.5)	43 (3.4)
Discrimination index		77	79	99	85
Y-3	A	13 (7.3)	106 (6.6)	116 (5.3)	125 (7.4)
	B	8 (1.7)	36 (32.6)	139 (19.7)	166 (14.7)
	X	158 (3.8)	187 (4.7)	166 (5.3)	170 (9.2)
Discrimination index		63	82	99	92
Y-21	A	83 (13.2)	79 (7.5)	42 (10.5)	61 (4.6)
	B	3 (1.2)	12 (14.8)	82 (8.1)	77 (5.1)
	X	68 (3.3)	69 (3.7)	64 (3.2)	67 (6.3)
Discrimination index		69	69	98	89
Y-22	A	52 (12.7)	44 (14.1)	46 (12.8)	59 (8.4)
	B	5.6 (1.1)	37 (7.2)	112 (17.6)	137 (6.8)
	X	142 (16.6)	134 (15.8)	151 (12.1)	151 (6.0)
Discrimination index		76	80	99	93

during Component X. During Phases 1, 2, and 4, this discrimination could occur only on the basis of the preceding stimulus (i.e., whether the preceding component had been A or B). The absolute response rates during Components X and Y are not shown because those during Component X were consistently high throughout the different phases of training and are thus uninformative. Response rates during Component X during the last five sessions of each phase can be seen in Table 1.

During Phase 1, in which no reinforcement was available during the target components themselves, all 4 subjects developed some pecking during the target components, primarily during Component A, which was followed by the VI 30-s schedule during Component X. For Subjects R-17 and Y-3, response rates were low, whereas for Subjects Y-21 and Y-22, substantial rates of responding occurred (Table 1). Despite the differences in absolute response rates across subjects, the results replicate those of Brown et al. (1982), and show that autoshaping does occur when the target stimuli predict different rates of reinforcement in their respective following components.

The effect of changing to Phase 2, in which the VI 2-min schedules were added during the target components, was to increase response rates during both target components, although response rates during Component A continued to be substantially higher than during Component B. The rate during Component A then decreased over training for 2 subjects (Y-21 and Y-22). The difference in response rates between Components A and B substantially decreased for Y-22, and perhaps would have reversed with continued training.

A major change in behavior occurred during Phase 3, in which the only procedural change was that the stimulus during Component Y, correlated with EXT, was changed from the vertical line to a small circle. This meant that differential stimuli now occurred in Components X and Y, correlated with the different following schedules. Over the course of training, all subjects reversed their patterns of responding, so that higher response rates occurred during Component B, followed by EXT, by the end of training. These results thus replicate previous studies of anticipatory contrast (e.g., Williams, 1979).

Phase 4 repeated the experimental conditions of Phase 2, in that the differential stimuli during Components X and Y were removed, leaving the white vertical line correlated with both the VI 30-s and EXT schedules. Despite the change in stimuli, the pattern of responding at the end of Phase 3 continued, in that higher response rates occurred during Component B, which was followed by EXT. This pattern was disrupted temporarily for Subject Y-21 during the first five sessions of training, because the rates were slightly higher during Component A in the first two sessions of Phase 4. In general, however, there was little indication that the pattern of responding during Phase 2 could be recovered.

Some effect of returning the stimulus in Component Y to the vertical line occurred with respect to the discrimination between Components X and Y. There was some disruption of the high level of discrimination that was occurring at the end of Phase 3 when differential stimuli were available, but substantial recovery occurred over the next series of sessions, although never to the level achieved in Phase 3. Nevertheless, the level of discrimination during Phase 4 was substantially greater than during Phase 2 (Table 1).

Because of the failure in Phase 4 to recover the pattern of behavior in Phase 2, it is important to establish that the pattern seen in Phase 2 was not due simply to inadequate exposure to the experimental conditions. Training during that condition was terminated after a fixed number of sessions rather than by a stability criterion, so it is possible that continued training might have produced a reversal in the pattern of responding. The critical issue, therefore, is whether the change in the pattern of response rates during Phase 3 was due to the addition of differential stimuli in Components X and Y, or due instead simply to additional training. To address this issue, the difference in response rates between Components A and B was calculated for the last two blocks of training during Phase 2 and for the first two blocks of training during Phase 3. Changes in the size of this difference thus reflect the effects of continued training. If continued training per se were the critical variable, this difference should change continuously, so that changes in the size of the difference between Blocks 4 and 5 of Phase 2 should be approximately the same as the changes in the size of the difference between Block 5 of Phase 2 and Block 1 of Phase 3 and the size of the differences between Blocks 1 and 2 of Phase 3. Alternatively, if the addition of the differential stimuli in Phase 3 were the critical variable, the size of the difference should change abruptly over the boundary separating the change in conditions. Table 2 shows the calculations for individual subjects. For 2 of the 4 subjects (Y-21 and Y-22), the size of the difference was similar for the last two blocks of Phase 2, and for Subject R-17 the change in the difference was in the opposite direction of that which occurred subsequent to the phase transition. For these subjects, the difference then decreased substantially (or reversed in sign) in going from Block 5 of Phase 2 to Block 1 of Phase 3, and decreased still further in going from Block 1 to Block 2 of Phase 3. Thus, these subjects offer little support for the view that the pattern of results seen in Phase 2 was due to inadequate training. In contrast, Subject Y-3 does offer some support for this possibility, because there was a substantial decrease in the difference between Blocks 4 and 5 of Phase 2, which was approximately the same size as the subsequent decreases that occurred between succeeding blocks of training.

Table 2

Differences in response rates (responses per minute) in Components A and B during the last two blocks of training in Phase 2 and the first two blocks of training in Phase 3. Negative numbers mean rates were higher in Component B.

Sub-	Phase 2		Phase 3	
ject	Block 4	Block 5	Block 1	Block 2
R-17	8.0	12.3	6.3	−11.7
Y-3	108.3	70.3	34.7	8.8
Y-21	68.8	66.4	46.1	30.6
Y-22	6.9	7.4	−6.0	−24.9

Because of the high level of discrimination occurring during Phase 4, the stimulus conditions were changed during Phase 5, in the hope of replicating the pattern of behavior obtained in Phase 2. The yellow and blue target keylights on the center key were changed to red and green keylights on the left side key, and the stimuli during Components X and Y were both vertical lines. Figure 2 shows the results of this change in stimulus conditions. For all subjects there was no differential behavior during the two target components of the first five sessions of training, indicating that the change in stimulus conditions required the subjects to relearn the sequence of the components of the multiple schedule. Then, over the course of training, response rate during the

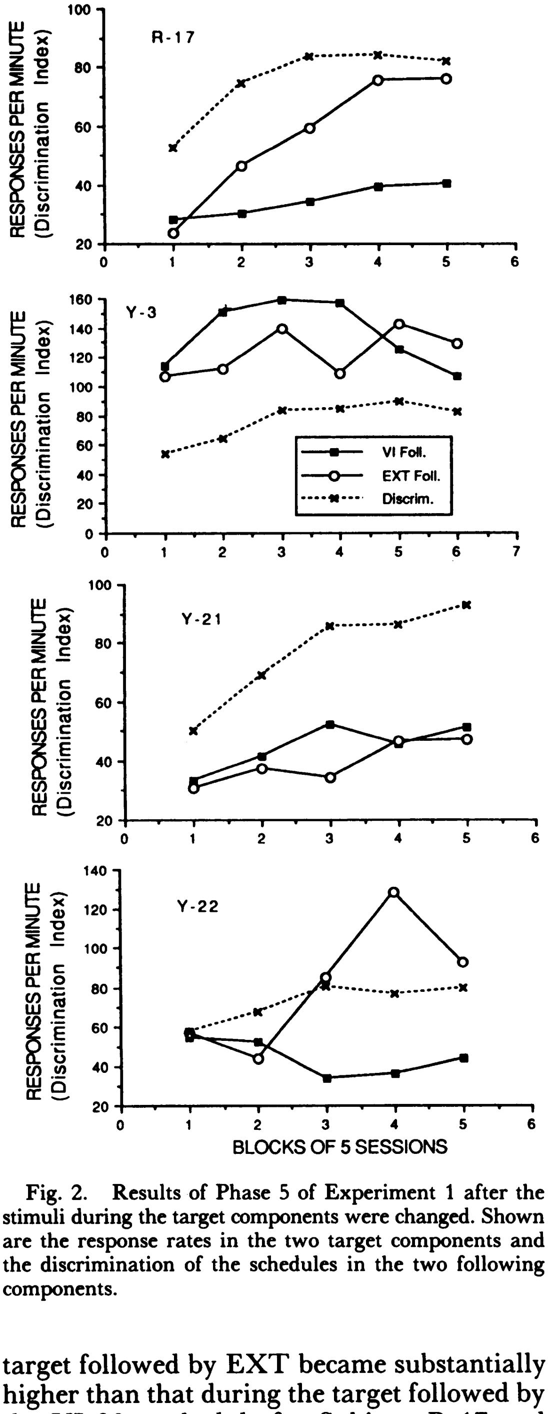

Fig. 2. Results of Phase 5 of Experiment 1 after the stimuli during the target components were changed. Shown are the response rates in the two target components and the discrimination of the schedules in the two following components.

target followed by EXT became substantially higher than that during the target followed by the VI 30-s schedule for Subjects R-17 and Y-22. For Subjects Y-3 and Y-21, there was initially a slightly higher response rate during Component A, followed by the VI 30-s schedule, but this difference either reversed (Y-3) with continued training or was abolished (Y-21). For all subjects, there was a gradual increase in the discrimination performance during Components X and Y, and there was little correspondence between the degree of discrimination and the pattern of response rates during the two target components.

Discussion

The results from the different phases of training replicate previous findings with similar procedures. When no reinforcement was available during the target components and their respective stimuli signaled different following schedules, autoshaping effects occurred, in that the target leading to the VI schedule generated substantial rates of responding, whereas the target leading to EXT did not. Such autoshaping effects due to differential prediction of reinforcement availability in the following schedule of reinforcement replicate the results of Brown et al. (1982). When reinforcement was available in the target components and the different following schedules were signaled by their own component stimuli, higher response rates occurred in the target component leading to EXT, thus replicating previous studies of anticipatory contrast (Nevin, Smith, & Roberts, 1987; Williams, 1979, 1981; Wilton & Gay, 1969). The intermediate condition, in which reinforcement was available during the target components but with no differential stimuli in the different following components, produced mixed results, depending upon the order of presentation of the different conditions. During Phase 2, which followed the autoshaping procedure of Phase 1, higher response rates occurred in the target component followed by the higher reinforcement rate, but during Phase 4, which followed the anticipatory contrast procedure, the contrast effects persisted with higher response rates in the target component followed by EXT. The attempt to reinstate the "autoshaping" effect with nondifferential stimuli in Phase 5 also produced mixed results: 3 subjects produced anticipatory contrast and 1 did not. Similar mixed results were obtained by Williams (1990).

The present results are similar to those reported recently by Hassin-Herman, Hemmes, and Brown (1992). In a four-component multiple schedule like that used here, they also varied the presence or absence of reinforcement in the target components and whether the different following schedules were signaled by the same or different stimuli. When the duration of their target components was very short (6 s), they found strong evidence for autoshaping effects during all conditions, although the interpretation of their results for the conditions in which reinforcement occurred in the target components is hindered because their subjects obtained almost no reinforcers during the target component that was followed by EXT. Then, when component duration was increased, anticipatory contrast became evident when reinforcement was available during the target components, both when the different following schedules were signaled by the same stimulus and by different stimuli. However, the size of the anticipatory contrast effect was larger when different signals were correlated with the different following schedules, as was the consistency of the effect across subjects. Thus, as in the present study, Hassin-Herman et al. found a continuum of effects from autoshaping to anticipatory contrast, with an intermediate pattern of results for the condition in which reinforcement was available during the target components but without differential stimuli during the different following schedules.

The reasons for the disparate results when differential stimuli were not available during the different following schedules in the present study are unclear. One possibility is the level of discrimination between the different target components. Such discrimination, which was necessarily based on the preceding stimuli correlated with the target components, was substantially greater in Phase 4 than in Phase 2. However, there was little correlation across subjects between the degree of the autoshaping effect and the level of discrimination, either in Phase 5 or in the previous study of Williams (1990). On the other hand, the results of Williams (1979, Experiments 2 and 3) do support a discrimination interpretation, in that removing the differential stimuli correlated with the different following schedules, after prior training on the anticipatory contrast procedure, completely abolished anticipatory contrast and produced the opposite, "autoshaping," pattern of results for all subjects tested. In that study the nondifferential stimulus condition was presented for only a few sessions, and discrimination performance during the different following schedules never increased beyond 55% to 60% correct.

A second possible interpretation of the difference between Phases 2 and 4 is that mere exposure to the stimulus contingencies of those conditions produced the switch from the autoshaping pattern of behavior to the anticipatory contrast pattern. Although this possibility cannot be excluded entirely from the present data, the analysis of the change in behavior between Phases 2 and 3 suggests that the addition of the differential stimuli in Phase 3 was the critical variable. In addition, previous work suggests that the continued exposure per se was not the controlling variable, because the subjects of Williams (1990) who showed the autoshaping pattern of behavior showed no evidence of a reversal in the pattern of behavior with continued training (see Figure 3 of that study). It should also be noted that the return to the nondifferential stimulus conditions during the two following components after exposure to differential stimuli, like that used in Phase 4 of the present study, does not necessarily produce the anticipatory contrast patterns of results. For example, Williams (1979, Experiments 2 and 3) presented a similar procedural change, and all 4 subjects in that study produced an autoshaping pattern in the nondifferential stimulus condition. Thus, the determinants of which pattern of behavior will occur remain mysterious.

It is important to recognize that the nondifferential stimulus condition used in Phases 2, 4, and 5 might or might not be expected to produce anticipatory contrast, depending on how the procedure is conceptualized. There clearly is a strong Pavlovian stimulus–reinforcer contingency arranged by the procedure, so the autoshaping effect should play an important role. But it is also the case that substantial discrimination of the reinforcement schedules in the different following components did occur for all subjects, and it is not obvious why there should be a difference between discriminative control due to the stimuli immediately present in the following components instead of remembering of the stimuli from the immediately preceding component. In both cases, a basis for identifying the different reinforcement schedules is available, so comparison between the different schedules should also be possible. At issue is how one conceptualizes the stimulus function played by the target stimuli correlated with the different following schedules. If the stimuli are regarded as Pavlovian CSs, then autoshaping effects should have occurred, but if they are regarded as operant discriminative stimuli, then anticipatory contrast should be expected. It is possible that the function of the stimuli changed over the course of training, in part as a function of the preceding conditions. In any event, it is clear that different outcomes may occur as a function of different orders of presentation of the different conditions, so that within-subject designs that randomize the presentations of the different conditions are likely to produce variable results, as was the case in the study by Williams (1990).

Despite the different results obtained in Phases 2 and 4, it is clear that the procedures used to study anticipatory contrast do contain an inherent Pavlovian stimulus–reinforcer contingency embedded within them, so that the dynamics of contrast effects must compete with such Pavlovian contingencies in order to become evident. The reversal in the pattern of behavior between Phases 2 and 3 shows that changes in the stimuli in the different following schedules can have a powerful effect on the outcome of this competition. When the different following schedules were correlated with their own cues, the signaling function of the target component stimuli became redundant, and thus presumably weakened the Pavlovian stimulus contingency to the point that contrast effects were dominant. Nevertheless, it seems likely that the Pavlovian stimulus–reinforcer relationship continued to play some role, thus reducing the level of anticipatory contrast from the level it might otherwise have reached. It thus becomes of interest to determine whether the effects of the Pavlovian contingency can be isolated functionally in order to determine what level of contrast is evident after its removal.

EXPERIMENT 2

Experiment 2 attempted to isolate the role of the Pavlovian stimulus–reinforcer contingency by adapting the "signal-key" procedure developed by Keller (1974). In this procedure, the stimuli for the different components of the multiple schedule are presented on one response key, and the response requirement occurs on a second response key correlated with a common stimulus across the different components of the schedule. To the extent that anticipatory contrast involves only operant behavior, such a procedure might simultaneously demonstrate the effect of the Pavlovian contingency with respect to signal-key behavior and anticipatory contrast on the operant key. Thus, Experiment 2 repeated the comparisons of Experiment 1. One group of pigeons received the order of presentation used in Experiment 1; a second group received the reverse order. In addition, the duration of the target components was 10 s for the first group and 30 s for the second group.

METHOD

Subjects and Apparatus

Eight White Carneau pigeons served as subjects and were maintained in all respects as those in Experiment 1. Here, however, all subjects had prior experience with several different schedules of reinforcement. The same apparatus was also used.

Procedure

All subjects were initially exposed to an autoshaping procedure in which the center response key was illuminated with a yellow keylight, followed by response-independent food. After all subjects were responding vigorously to this stimulus, they were begun immediately on a four-component multiple schedule similar to that used in Experiment 1, in which Target Components A and B were followed by Components X and Y, with the A-X and B-Y pairs randomly interspersed throughout a session. Unlike the procedure in Experiment 1, however, separate response keys were used for the operant requirement (center key) and the location of the stimuli that cued the different components of the schedule (left key).

Group 1. During the initial phase of training, no reinforcement was available during Components A and B; a VI 30-s schedule was in effect during Component X and EXT occurred during Component Y. Reinforcement during Component X occurred only with respect to responding to the center key; responding to the left key had no scheduled effect at any time during training. Red and green on the left key served as the cues for the two target components, with the assignment of the particular color to the component counterbalanced over subjects. During all four components, the center response key was illuminated with a yellow keylight. The stimulus on the left signal key during Components X and Y was a white horizontal line. Component duration was 10 s for Components A and B and 30 s for Components X and Y. Training during Phase 1 continued for 40 sessions, each approximately 33 min in duration.

During Phase 2 the same stimulus conditions were continued, with the only change being the addition of a VI 2-min schedule during Target Components A and B. Reinforcement was contingent on pecks to the center key, as it was during Component X. Training continued for 25 sessions.

During Phase 3, the same reinforcement schedules were continued, with the only change being the stimulus conditions during Component Y. Now a white vertical line was presented on the left key, and the yellow keylight continued on the center key. Thus, the stimuli for Components X and Y were now a horizontal and a vertical line, respectively, on the left key; the yellow keylight continued on the center key during all components. Training during Phase 3 continued for 30 sessions.

Group 2. These subjects first received the condition with differential stimuli correlated with Components X and Y. During all components, yellow was projected on the center key, pecks to which produced reinforcement when available. The stimuli on the left key were red or green during Components A and B, the horizontal white line during Component X, and the vertical white line during Component Y. The reinforcement schedules for pecks to the yellow center key were VI 2 min for Components A and B, VI 30 s for Component X, and EXT for Component Y. Component duration was 30 s for all four components. Training continued in Phase 1 for 25 sessions.

During Phase 2, the stimulus correlated with Component Y was changed from the vertical to the horizontal line, thus making its stimulus conditions the same as for Component X. The reinforcement schedules in all components remained the same. Training in Phase 2 continued for 30 sessions.

During Phase 3, the VI 2-min schedules of the two target components were replaced with EXT. All stimulus conditions remained the same as in Phase 2. Training continued for 25 sessions.

Results

Group 1

On the left side of Figure 3 are the response rates to the operant (center) key, which was always illuminated with the same stimulus; on the right side are the rates to the signal key. Only the response rates during the two target components are shown for the operant key, because response rates during Component X continued at a high rate throughout training. Also shown for the operant key are the discriminations between Components X and Y, calculated as the percentage of the total responses during those components that occurred during Component X. The right side of Figure 3 shows the response rates to the signal key for all four components.

The anticipated pattern of results in Phase 1 was that any behavior that occurred during the target components would occur primarily to the signal key, because no reinforcement was available for operant-key responding during the target components themselves. Thus, any behavior that was generated would be due to the Pavlovian stimulus contingency, which only applied to the differential stimuli presented on the signal key. Pecking to the signal key did occur for 3 of 4 subjects, whereas the remaining subject (B-30) had some signal-key behavior during the first 10 to 20 sessions, which then decreased to a very low level for the remainder of the experiment. Substantial signal-key behavior occurred during Component A for the remaining 3 subjects, but little signal-key pecking occurred during Component B. Thus, the Pavlovian stimulus–reinforcer contingency was effective in controlling signal-key behavior. In addition, substantial signal-key behavior also occurred during Component X for B-3 and Y-18, and, oddly, during Component Y for B-64. It should be noted that a differential signal–reinforcer contingency did exist for the white horizontal line that appeared on the signal key during both Components X and Y. Because the rate of reinforcement during Component X was a VI 30-s schedule and that during Component Y was EXT, the average rate of reinforcement in the presence of the horizontal line was VI 60 s, and EXT was in effect during the remaining two components of the schedule.

In addition to the signal pecking during Components A and B, substantial response

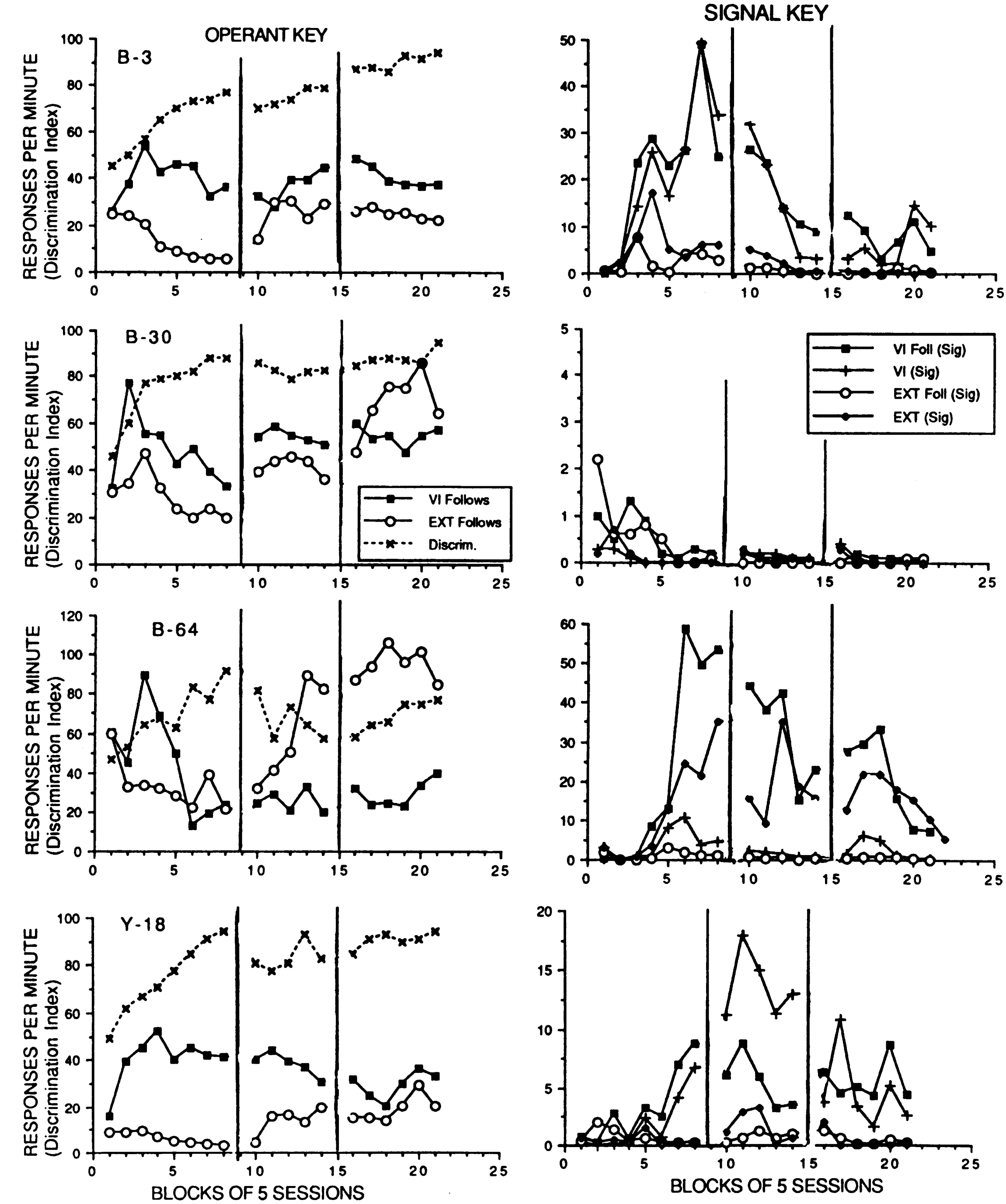

Fig. 3. Results for individual subjects in Group 1 of Experiment 2. Graphs on the left side depict response rates to the operant key as well as the discrimination of the schedules in the two following components. Graphs on the right side depict response rates to the signal key for all four components. Target Components A and B are designated by VI Foll and EXT Foll, respectively, and Components X and Y are designated by VI and EXT. Sections of each graph separated by the vertical lines correspond to Phases 1 through 3 of training.

rates occurred to the operant key for all 4 subjects, despite there being no reinforcement for such behavior. In fact, operant-key response rates were higher than the signal-key rates for 3 of the 4 subjects. One possible source of operant-key pecking during Phase 1 was stimulus generalization from reinforced responding to the operant key during Component X. Given that the yellow keylight was present on the center key for all four components, substantial responding to the center key would be expected in all components to the extent that the different components failed to be discriminated. Accordingly, responding to the operant key should be similar for the two target components, because the degree of stimulus generalization should be equivalent in both cases. But substantially greater responding occurred in Target Component A than in Target Component B for 3 of the 4 subjects. The remaining subject (B-64) had similar response rates to the two target components by the end of training, although higher response rates also occurred in Component A for that subject during the first 20 to 25 sessions of training. Thus, the differential Pavlovian signal contingency affected behavior during the target components to the operant key as well as to the signal key.

The procedural change during Phase 2 was to add reinforcement schedules during the two target components. Response rates to the operant key increased during Component B for all subjects, whereas those during Component A remained relatively stable. Response rates continued to be higher in Component A than in Component B for 3 of the 4 subjects, but the remaining subject (B-64) developed anticipatory contrast during this phase, responding with higher rates in Component B than in Component A.

The effect on signal-key pecking of adding the reinforcement schedules in Phase 2 was to decrease response rate during Component A for all subjects that had substantial rates at the end of Phase 1. Responding to the signal key during Component X also decreased for B-3 but increased for Y-18. Signal-key responding during Component Y for B-64 continued relatively unchanged.

Addition of differential signals for Components X and Y in Phase 3 produced anticipatory contrast for B-30 and continued the contrast pattern from Phase 2 for B-64. Little change in operant-key responding occurred for B-3, whereas the difference between response rates during the two target components decreased but did not reverse for Y-18. Little change in signal-key responding as a function of the stimulus change was evident, except that signal-key responding during Component X decreased for Y-18. By the end of Phase 3, signal-key response rates were at low levels for all subjects, but were also higher during Component A than during Component B when responding did occur.

Table 3

Response rates (responses per minute) during the last five sessions of each condition for Group 1 in Experiment 2, separated by component and response key.

Subject	Phase	Operant key A	B	X	Y	Signal key A	B	X	Y
B-3	1	36	6	52	15	25	3	34	6
	2	44	30	56	15	9	0	3	1
	3	38	22	62	4	5	0	10	0
B-30	1	33	20	86	11	0	0	0	0
	2	51	37	87	18	0	0	0	0
	3	57	64	98	5	0	0	0	0
B-64	1	24	22	55	5	54	4	1	35
	2	20	82	45	35	23	0	1	6
	3	39	85	54	16	7	0	0	5
Y-18	1	41	3	47	3	9	0	7	0
	2	31	20	38	8	4	1	13	1
	3	33	20	41	3	5	0	3	0

Because of the variability across subjects in the pattern of both operant- and signal-key pecking (Figure 3), it is worthwhile to determine if some correlate of behavior predicts the pattern that was observed. To assess better the relationship between the various measures, Table 3 shows the response rates in the four components for both the signal and operant keys during the last five sessions of each condition. A possible scenario was that the maximum anticipatory contrast effect would occur for subjects with strong signal-key behavior, where presumably the Pavlovian and operant determinants of responding were separated functionally. That is, to the extent that the Pavlovian component of behavior was located on the signal key, the anticipatory contrast effect would be more evident with respect to operant-key behavior. One of the subjects showing anticipatory contrast (B-64) did exhibit such a pattern of behavior, in that the occurrence of anticipatory contrast during Phase 2 occurred in conjunction with substantial signal-key behavior. However, the remaining subject showing anticipatory contrast (B-30) displayed no signal-key behavior. Moderate signal-key response rates occurred for the remaining 2 subjects that did not produce anticipatory contrast on the operant key, so no consistent relation occurred between signal-key behavior and anticipatory contrast.

A second possible correlate of the different patterns of behavior was the degree of discrimination of the schedules during Components X and Y. For all subjects the degree of discrimination was greater during Phase 3 than during Phase 2, but across subjects there was no correlation within either phase between the level of discrimination and the occurrence of contrast. For example, B-64 displayed the poorest discrimination but demonstrated the largest contrast effect in both phases.

An unexpected feature of the results was the deterioration in discrimination behavior with the transition between Phases 1 and 2. For 3 of the 4 subjects, the degree of discrimination significantly worsened during Phase 2, despite continued training with the same relation between the stimuli in Components A and B versus the schedules in Components X and Y. Such deterioration indicates that the addition of reinforcement during Phase 2 somehow interfered with the discriminative control exerted by the A and B stimuli.

Group 2

Some of the effects seen in Figure 3 possibly could be due to the effects of continued training independent of the change in experimental conditions. To control for this possibility, Group 2 received the opposite order of presentation. In addition, the duration of the target components for Group 2 was 30 s, in contrast to the 10-s durations used for Group 1.

The expected pattern of results during Phase 1 was an anticipatory contrast effect with respect to operant-key responding. Figure 4 shows that anticipatory contrast did occur for Subjects R-11 and R-25, in that response rates were higher during Component B followed by EXT. However, the opposite pattern occurred for R-31, and no meaningful difference in response rates occurred for R-1. Thus, the results for operant-key responding were similar to those in Phase 3 for Group 1, in which only some of the subjects exhibited the anticipatory contrast effect.

The similarity in operant-key behavior for Groups 1 and 2 occurred despite substantial differences with respect to signal-key behavior. Two of the 4 subjects had little signal-key behavior by the end of Phase 1, whereas the remaining 2 subjects (R-1 and R-25) responded to the signal key primarily during Component X, where the signal served as a cue for the VI 30-s schedule. This responding then also ceased during Phase 2, when the differential signals during Components X and Y were removed, so that no subjects were exhibiting significant signal-key behavior to any of the keys by the end of Phase 2.

The change to nondifferential signals in Components X and Y in Phase 2 produced changes in the pattern of operant-key behavior during the target components. Subject R-1 continued to show little difference in rate between the two components, but the difference in favor of Component A continued and was increased for R-31. The remaining 2 subjects, which both had shown anticipatory contrast in Phase 1, now reversed that pattern, although the difference in favor of Component A was small for R-25. Table 4 shows the results from the last five sessions of each phase, and shows that for all subjects the effect of the stimulus change was to increase response rate differentially in Component A, although the size of this effect was variable across subjects.

The change in reinforcement schedules to EXT in the two target components during Phase 3 produced consistent effects for all subjects. Response rates in both target components decreased regularly over the course of training, and for all subjects, response rate was higher in Component A at all points during training. Comparing the response rates during Phase 3 for Group 2 (Table 4) with those from Phase 1 for Group 1, it is clear that the response rates to the target components were much lower for Group 2. This possibly could be due to the different orders of presentation of the different experimental conditions, but a more likely explanation is that the duration of the target components was three times longer for Group 2 (30 vs. 10 s) so that their signal value should be substantially weaker. This is shown more clearly with respect to signal-key behavior during Phase 3 for Group 2, in that only 1 subject (R-11) displayed any signal-key behavior during the target components, and that occurred at very low rates (less than five responses per minute). This subject also had a similar signal-

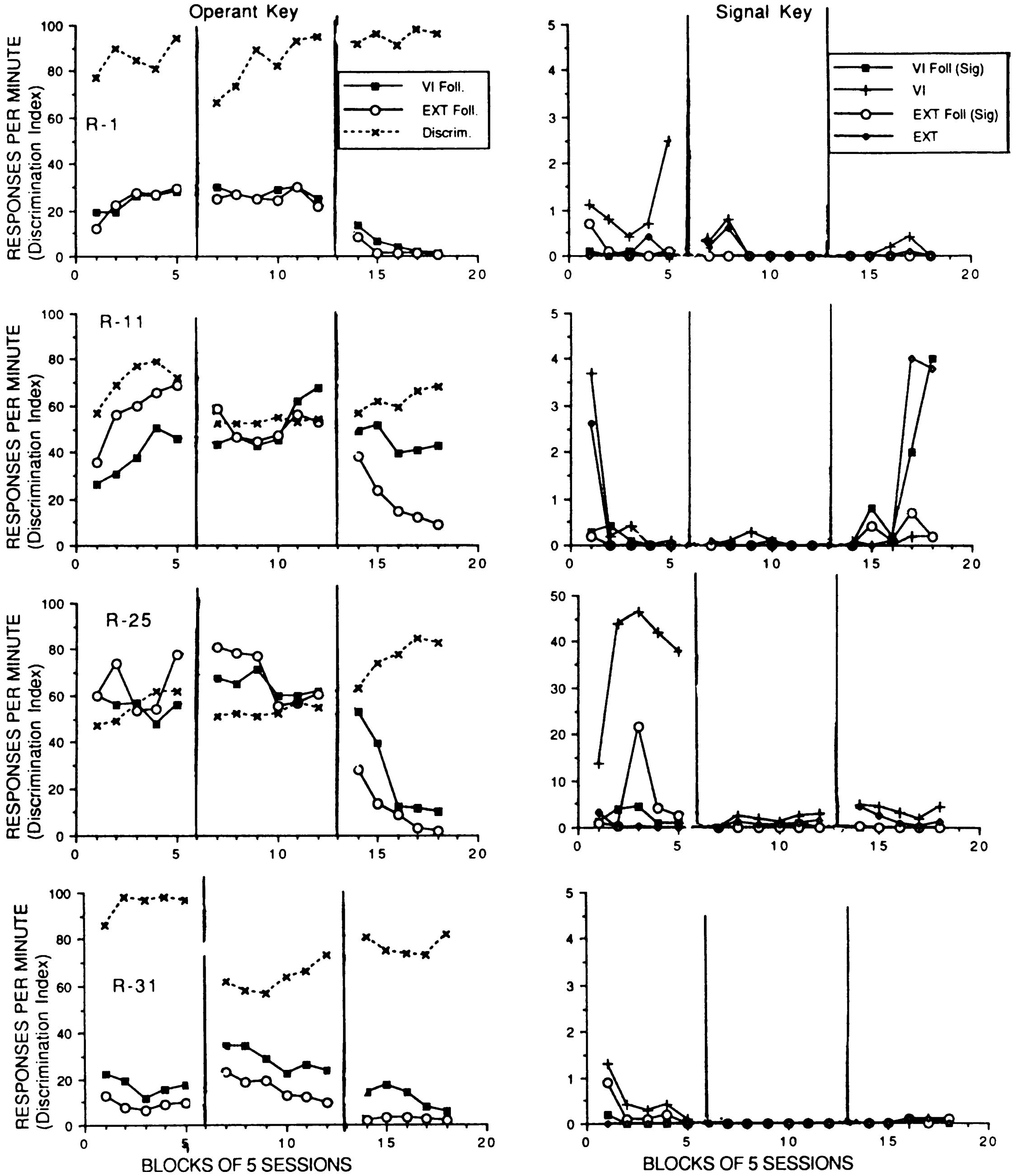

Fig. 4. Results for individual subjects in Group 2 of Experiment 2. Graphs on the left side depict response rates to the operant key as well as the discrimination of the schedules in the two following components. Graphs on the right side depict response rates to the signal key for all four components. Target Components A and B are designated by VI Foll and EXT Foll, respectively, and Components X and Y are designated by VI and EXT. Sections of each graph separated by the vertical lines correspond to Phases 1 through 3 of training.

Table 4

Response rates during the last five sessions of each condition for Group 2 in Experiment 2, separated by component and response key.

Subject	Phase	Operant key A	B	X	Y	Signal key A	B	X	Y
R-1	1	28	29	45	3	0	0	3	0
	2	25	21	45	3	0	0	0	0
	3	1	0	46	2	0	0	0	0
R-11	1	46	69	61	24	0	0	0	0
	2	68	53	91	76	0	0	0	0
	3	43	9	116	54	4	0	0	4
R-25	1	56	78	59	37	1	3	38	0
	2	62	60	75	61	0	0	3	2
	3	10	2	75	15	0	0	5	1
R-31	1	17	9	48	1	0	0	0	0
	2	24	9	32	12	0	0	0	0
	3	6	2	55	12	0	0	0	0

key rate during Component Y, as did Subject B-64 in Group 1 in the corresponding condition.

Table 4 and Figure 4 allow an assessment of the relation between the pattern of behavior during the target components and the degree of discrimination during Components X and Y. Discrimination levels decreased for all subjects after the change to Phase 2; this change was accompanied by the switch from an anticipatory contrast pattern to an autoshaping pattern. However, within Phase 1 itself, subjects that showed the clearest anticipatory contrast in Phase 1 (R-11 and R-25) displayed the poorest discrimination, although at least part of this effect for R-25 may have been due to response competition from signal-key pecking during Component X. Thus, as in Phase 1, there appears to be no clear relation between the degree of discrimination and the pattern of behavior during the target components.

Discussion

The rationale of Experiment 2 was to separate topographically the behavior controlled by the Pavlovian stimulus–reinforcer contingency from the operant behavior subject to anticipatory contrast. The expected pattern of results was that responding to the signal key would vary systematically with the strength of the Pavlovian contingency (e.g., whether the target component stimuli were the only predictors of the differential following schedules), whereas behavior to the operant key would reflect only the dynamics of contrast. It is clear from Figures 3 and 4 that these expectations were not fulfilled. Instead, behavior to the operant key was also strongly influenced by the Pavlovian contingencies, so that the pattern of responding was often similar to that obtained in Experiment 1 when the component stimuli were located on the response key with the operant contingency. Thus, for Group 1 in Phase 1 and Group 2 in Phase 3, responding to the operant key was generally higher during the target component followed by the VI 30-s schedule. During Phase 2 for both groups, this effect of the Pavlovian contingency was also evident for the majority of subjects, because response rate was higher in the target component followed by the VI 30-s schedule. Behavior to the signal key was as predicted, in that more pecking occurred to the signal key during Component A than Component B throughout training, given that any degree of key pecking occurred in either target component. However, signal-key pecking generally declined over training for Group 1 and generally failed to occur for Group 2.

The effects of the Pavlovian stimulus–reinforcer contingency on operant-key behavior during the target components are perhaps not surprising given that previous analyses of the signal-key procedure have found that it does not provide the clear separation of elicited versus operant behavior for which it was originally implemented. Williams and Heyneman (1981) reviewed the previous studies using the procedure and noted that significant pecking to the signal key in two-component multiple schedules generally failed to occur when a changeover delay (COD) was instituted that prevented reinforcement of operant-key pecking shortly after a signal-key peck. The efficacy of the COD presumably was due to the prevention of adventitious reinforcement of signal-key pecking, which implies that the stimulus–reinforcer contingency was, at best, only partially responsible for signal-key behavior. However, the pattern of behavior obtained here is the reverse of that described by Williams and Heyneman, in that here operant-key responding was affected by the Pavlovian signal contingency rather than signal-key responding being affected by the operant contingency.

It is possible that adventitious reinforcement played some role in the present results, but several features of the results make it implausible. The high rates of operant-key behavior to Component A but not to Component B during Phase 1 for Group 1 cannot easily be explained by the notion of adventitious reinforcement, because no reinforcement was available during those phases for responses to either the signal or operant keys. It is possible that reinforcers occurring in Component X could have reinforced operant-key pecking in Component A, but most reinforcers during Component X would have occurred temporally distant from the offset of Component A. Nevertheless, the duration of the target components appears to be critical, because relatively low levels of operant-key pecking occurred for Group 2 when no reinforcement was available during the target components (Phase 3 in Figure 4), and this behavior declined regularly with continued training in that procedure. The most likely source of the difference between Groups 1 and 2 was that the target components for the former were 10 s in duration and those for the latter were 30 s. Perhaps the longer duration target components lessened the effect of the onset of Component X on responding during the target components. It is important to note, however, that the onset of the horizontal line correlated with Component X could not itself provide adventitious reinforcement that was differential for the two target components, because in two of the three phases of training it was associated with both following components.

If adventitious reinforcement is not the explanation of the control of operant-key behavior by the Pavlovian contingencies, what then is an alternative? One possibility is that the subjects learned a conditional discrimination such that the value of the yellow keylight on the operant key was different as a function of the signal-key stimulus that accompanied it. Thus, in the presence of the signal-key cue that was followed by the VI 30-s schedule in Component X, the yellow keylight served as a Pavlovian CS+, so that responding was generated despite the absence of reinforcement in the target component itself. Such conditional discrimination may seem implausible, because it would be more straightforward for the subject's behavior to be controlled by the stimulus on the signal key as the Pavlovian CS+, rather than for it to serve as a conditional cue. It should be noted, however, that there is no reason that the stimulus on the signal key could not serve both functions simultaneously. If both functions were being served, the expected result would be responding to both the signal and operant keys in Component A, which was in fact the pattern obtained in Phase 1 for Group 1. The finding that much less behavior occurred for Group 3 under the corresponding conditions might then be due to the longer duration target components being less effective as Pavlovian CSs.

A troublesome feature of the results of Experiment 2 was the failure to obtain clear anticipatory contrast for all subjects during the conditions in which different discriminative stimuli were correlated with all four components of the schedule. Only 4 of the 8 subjects developed higher response rates to the target followed by EXT in Phase 3. In comparison, all 4 subjects displayed anticipatory contrast in the corresponding condition of Experiment 1 (see Phase 3 in Figure 1). A possible explanation for the erratic display of contrast in Experiment 2 can be described in terms of stimulus similarity between the target components and their respective following schedules. As demonstrated by Williams (1988), anticipatory contrast is more evident when the stimuli are maximally dissimilar, and may not occur at all when a high level of stimulus similarity exists. The stimuli used in Experiment 2 of the present study were more similar than those used in Experiment 1, because the target and following components shared the common yellow keylight on the operant key at all times. Thus, even though the stimuli on the signal key were quite different for the targets and their respective following components, the occurrence of the common stimulus on the operant key substantially increased the stimulus generalization between the components, which in turn may have reduced the level of anticipatory contrast.

The present results, with previous findings using related procedures, establish that the Pavlovian contingencies play an important role in anticipatory contrast procedures. Stimulus–reinforcer contingencies are dominant when no reinforcement is available during the target components. Just when, and under what circumstances, such contingencies will continue to be manifested when reinforcement is added in the target components continues to be unclear, because there appears to be a graded effect that affects individual subjects in different degrees. Depending on the stimulus conditions in the following components and the stimulus similarity between the target components and the following components, either Pavlovian or contrast effects may dominate. However, Pavlovian and contrast effects were so strongly intertwined in the present results that little encouragement is offered for the prospect of separating these different contingencies. That is, the Pavlovian contingencies had stronger effects on operant-key behavior than on signal-key behavior, despite the fact that the signal key provided the only discriminative information about the schedules in the different following components.

Given the strong Pavlovian effects that are evident here, the remarkable finding is that anticipatory contrast ever occurs in procedures with such embedded Pavlovian contingencies. That is, in order for the subjects to respond differentially in the target components, they must discriminate the predictive relation between the stimuli in the target components and their respective following schedules. The anomaly of the present experiments is that strengthening this predictive relationship counteracts the development of anticipatory contrast, but its complete absence serves the same function. Just how the stimulus functions served by the target stimuli should be conceptualized remains to be determined.

REFERENCES

Brown, B. L., Hemmes, N. S., Coleman, D. A., Jr., Hassin, A., & Goldhammer, E. (1982). Speciation of the stimulus-reinforcer relation in multiple schedules: Delay and probability of reinforcement. *Animal Learning & Behavior,* **10,** 365–376.

Hassin-Herman, A. D., Hemmes, N. S., & Brown, B. L. (1992). Behavioral contrast: Pavlovian effects and anticipatory contrast. *Journal of the Experimental Analysis of Behavior,* **57,** 159–175.

Keller, K. (1974). The role of elicited responding in behavioral contrast. *Journal of the Experimental Analysis of Behavior,* **21,** 249–257.

Nevin, J. A., Smith, L. D., & Roberts, J. (1987). Does contingent reinforcement strengthen operant behavior? *Journal of the Experimental Analysis of Behavior,* **48,** 17–33.

Williams, B. A. (1979). Contrast, component duration, and the following schedule of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes,* **5,** 379–396.

Williams, B. A. (1981). The following schedule of reinforcement as a fundamental determinant of steady state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **35,** 293–310.

Williams, B. A. (1988). The effects of stimulus similarity on different types of behavioral contrast. *Animal Learning & Behavior,* **16,** 206–216.

Williams, B. A. (1990). Pavlovian contingencies and anticipatory contrast. *Animal Learning & Behavior,* **18,** 44–50.

Williams, B. A., & Heyneman, N. (1981). Determinants of contrast in the signal-key procedure: Evidence against additivity theory. *Journal of the Experimental Analysis of Behavior,* **35,** 161–173.

Williams, B. A., & Wixted, J. T. (1986). An equation for behavioral contrast. *Journal of the Experimental Analysis of Behavior,* **45,** 47–62.

Wilton, R. N., & Gay, R. A. (1969). Behavioral contrast in one component of a multiple schedule as a function of the reinforcement conditions operating in the following components. *Journal of the Experimental Analysis of Behavior,* **12,** 239–246.

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